Chile

Skyline of downtown Santiago, the capital of Chile, featuring 300-meter high Gran Torre Santiago, the tallest skyscraper in Latin America, and Mapocho River, which divides the city in two parts. Photo credit: ©iStock.com/Phototreat.

"Chile's extreme geography, with landscapes including Earth's driest desert and the largest ice fields in the Southern Hemisphere outside Antarctica, poses complex challenges for water resource management. Chilean cities development occurs in a historical context characterized by increasing awareness on the importance of inclusive access to goods and ecosystem services, as well as of equal opportunities for human development; water is a specially important factor for achieving these objectives"

Water Security in Chile's Cities: Advances and Pending Challenges

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Summary

As it happens in many urban centers around the world, Chile's urban water sector seeks to attain water security[1] by means of enhancing water's productive potential while at the same time minimizing its destructive force through urban water systems. Chile's historical evolution shows a trajectory of success, with significant improvements in access to safe drinking water supply, sewage collection and treatment, with private services provision and effective public oversight. These improvements have reduced significantly the incidence of water-borne infectious illnesses in the population. Despite the above, outstanding challenges persist, including local water quality problems related to Chile's geology; the need for integrated and sustainable urban and natural water system management for quantity and quality; and the need for increasing water services access for population living in peri-urban environments. Given that the majority of Chilean cities are located in water-scarce areas, or in regions where climate change is expected to generate important drying effects in the long term, it is urgent to address these challenges with both existing and new, effective management tools.

1. Introduction

Eighty-nine per cent of Chile's population currently live in cities, which is more than both the world average of 54% and the 80% who inhabit cities in Latin America and the Caribbean, the estimated percentage of city dwellers for 2050

1. Water Security is understood here in keeping with the United Nations definition that it is the population's capacity to maintain sustainable access to sufficient amounts of water of acceptable quality to support the life, wellbeing and economic development of the population to ensure protection from the pollution of water systems and water-related disasters, and to preserve ecosystems in a climate of peace and political stability.

being 93% (United Nations, 2014). As with many of the world's cities, legislation in Chilean cities seeks to achieve water security, by increasing the productive potential of water and minimizing its destructive potential through Urban Water Systems, whether public or private. Chile's enormous geographic diversity means that its cities face a wide range of water security threats, from the hyperaridity and competition between users faced by cities in the north of the country through shortages and seawater intrusion in coastal cities to flooding in the southern zone and local water quality problems of various origins.

Generally speaking, cities can have stable areas or be in a state of expansion (as in the case of Chile). The former typically have an established service infrastructure, although the level of achievement of their objectives may be incomplete. Among the latter, it is often necessary to develop infrastructure quickly through processes that are not always compatible with the rest of urban development, placing excess pressure on existing systems. Although lack of infrastructure may be viewed as a weakness, it can also be seen as an opportunity to develop innovative solutions, taking into account the experiences of other cities, and new knowledge of rapid global changes such as climate change. Chile's experience is presented below, with a focus on three main issues: i) the institutional experience of the sanitation sector; ii) the challenges of sustainable rainwater management; and iii) the expected impact of climate change and the first steps towards adapting to it.

2. Governance and Sanitation Sector Management in Chile

Valenzuela and Jouravlev (2007) identify four historical phases in the development of Chile's sanitation sector. The first phase, from 1950 to 1974, was characterized by sanitation service provision by the state alone. Within the historical context of the time, public companies did not sufficiently distinguish between their supervision and service functions; users were not charged the real price of services, there was a high level of unfocussed subsidies, and investment decisions competed with other state needs. This phase saw the creation of the Directorate of Sanitation Works (DSW) in 1953, as a result of the merging of the Department of Hydraulics of the Ministry of Public Works (MPW) and the Directorate of Drinking Water and Sewerage of the Ministry of the Interior. Although the DSW was nominally the only entity with the mission of developing urban fresh water and sewerage services, in practice it shared responsibilities with other state departments, a characteristic of the Chilean water sector that has survived to this day (World Bank, 2012).

The second phase, from 1975 to 1990, coincides almost exactly with the duration of the military government (1973-1990). This period was marked by an emphasis on the liberalization and deregulation of various markets in order to reduce inflation and achieve a macroeconomic balance. Moreover, there was a drive by the authorities to limit the state's role to oversight and subsidization functions. Of particular importance during this period was the Water Code, enacted in 1981. Among other things, it established the private nature of water use rights, making it possible to reassign water through market transactions. Although several public companies were privatized during this phase, the sanitation sector remained under state control, and it was decided to perfect the system. At the institutional level, in 1977, the National Sanitation Works Service (NSWS) was founded, bringing together various scattered services at the national level. The NSWS was an autonomous territorially decentralized state institution. It had a national directorate and eleven regional offices in addition to overseeing two state companies specifically created to serve the cities of Santiago, the Metropolitan Sanitation Works Company (MSWC) and the Valparaiso Sanitation Works Company (VSWC). Various authors agree that this structure made it possible to significantly increase the efficiency of the system and promote a major increase in coverage during this phase. This was achieved by reducing the number of staff, increasing the flexibility of decision-making, and promoting greater transparency and better use of resources (Salazar, 2003; Alegría and Celedón, 2004; Fischer and Serra, 2004). In financial terms, this phase was marked by change, including increased collection through stricter billing policies, outsourcing, progressive increases in rates together with subsidies targeting low income sectors. The drive to modernize the billing system was particularly important. The process underwent several iterations before converging on a general regulatory scheme implemented during the third historical phase. At the end of the second phase, a new regulatory framework was created through the enactment of the Sanitation Services Rates Law and the General Sanitation Services Law (1988) the Law for the Subsidization of Fresh Water Consumption and Sewerage Service Fees (1989) and the law that created the Sanitation Services Superintendence (SSS) (1990). Moreover, during this period the state was allowed to undertake business activities related to drinking water and sewerage, for which the NSWS and the MSWC and VSWC offices became public limited companies with majority shares in the Economic Development Agency (EDA).[2] Although the implicit objective of these transformations was the privatization of sanitation companies, in practice, the process was not completed until some years later.

The third phase, from 1991 to 1994, was characterized by a system of public companies operating under a scheme devised for private companies. The government of the time decided to suspend the privatization fostered by the regulatory changes implemented at the end of the military government and instead encouraged improvements to the management of these companies using the tools available. A key step involved setting prices according to development costs, together with targeted subsidies, which increased the companies` profitability with minor political costs. With the gradual increase in rates, by 1997, all the state sanitation companies were generating profits and contributing funds to the State Treasury for financing of other social programs (Alegría and Celedón, 2004). By 1995, the MSWC's net annual profits were approximately 11% higher than its total assets. This ideal situation was partly due to the country's solid economic performance, which meant that people had higher incomes and were more willing to pay for drinking water and sewerage services. This phase was also characterized by the start of SSS's operations, meaning that there was a state agency overseeing publicly owned companies.

2. EDA is a state body tasked with promoting productive development.

The fourth phase, which began in 1995 and has continued until the present, corresponds to the privatization of the public sanitation companies existing in 1994. The government of the time justified the decision to privatize these companies by citing the need to increase their investment capacities and meet the country's growing need for wastewater treatment services.

This issue was perceived as a debt that had dogged the public companies in the sector which, although they had notably increased coverage of drinking water provision and wastewater collection services in previous decades, had failed to achieve a similar level of success in wastewater treatment coverage. Likewise, it was argued that the state would thereby use the public funds required for financing social programs to invest in infrastructure that could be covered by private capital. Between 1995 and 1998, triggered partly by specific events that created a public scandal, measures were taken to correct the laws enacted in previous years.

Thus, in 1998, the Law of Sanitation Service Rates was modified, together with the General Law on Sanitation Services and the Law on Sanitation Service Supervision. The state was to control 35% of regional sanitation companies, a percentage which could be reduced if this did not contribute to capital increases. Despite this, the state would be able to maintain veto power over certain decisions provided its share was over 35% or else for 10 years after the moment when its share first fell below 35% of the capital with the right to vote, as long as its share was equal to or greater than 10%.

The modifications can be summarized as follows:

- Strengthening the SSS with greater resources, autonomy and skills and increased control measures. Of particular interest was the modification of the regime of sanctions for companies failing to fulfill their obligations.
- The participation of companies providing other public services, operating within the same concession territory of a sanitation company was restricted, thereby preventing the institutional concentration of basic services.
- Restrictions on company ownership were introduced to prevent the formation of monopolies and encourage comparative competition.

- Transactions with related companies were regulated.
- Measures were adopted to regulate conflicts of interest and prevent the manipulation of information.
- The procedure for conflict resolution was improved.
- The process and methodology for tariff setting was improved and made transparent.

Aspects of Sanitation in Urban Sectors: Drinking Water Provision and Wastewater Management

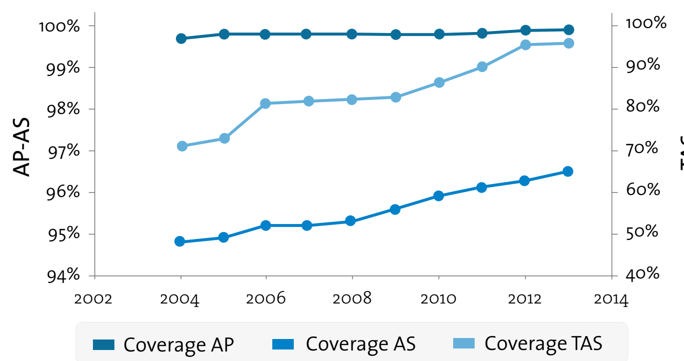
Service Coverage

Drinking water and sewerage infrastructure coverage has reached high levels in Chile. The World Health Organization (WHO) and UNICEF document entitled Drinking Water and Sanitation (updated 2014) states that Chile met the United Nations Millennium Development Goals for both drinking water and sanitation for the whole population (UNICEF/WHO, 2014). The total population (urban%) of Chile rose from 13.2 (83%) to 17.5 (89%) million inhabitants between 1990 and 2012. Sanitation coverage increased from 91% to 100% in urban areas, with access to improved drinking water sources rising from 99% to 100% during the same period.

Figure 1 shows the evolution of drinking water coverage, the sewerage network and wastewater treatment services for the past 10 years (2004-2013). In 2013, drinking water coverage was 99.9%; the regions with the lowest coverage being Araucanía (99.8%), Atacama (99.7%), Coquimbo (99.7%) and Valparaíso (99.4%); sanitation coverage is 96.5% with a minimum of 88.2% in the O'Higgins region, while 99.9% of the population are connected to the sewerage system and wastewater treatment services. Maule is the only region where the entire volume of collected wastewater is not treated (98.4%) (SISS, 2013a).

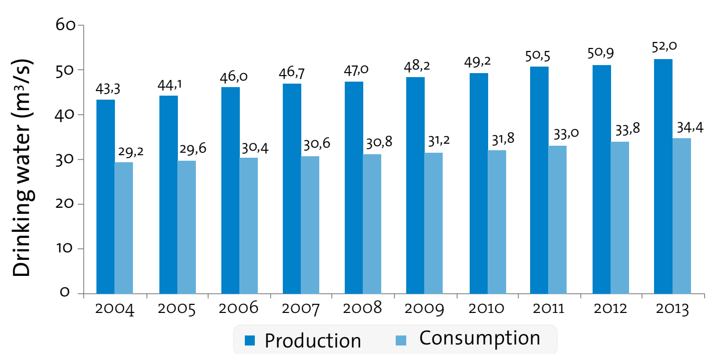
In 2013, sanitation companies produced a total of 1,639,247 thousand m^3 (equivalent to ~52 m^3/s), of which an average of 33.7% were not billed, corresponding to losses in the production and distribution phases (SISS, 2013b). Figure 2 shows the evolution across time of average water production by sanitation companies and average water

Figure 1. Urban coverage for drinking water (PW), sewerage (S) and wastewater treatement (WWT) between 2004 and 2013.



PW and S coverage can be read along the left vertical axis, and WWT coverage can be seen along the right vertical axis. 2004-2013. Las The calculation was made with consideration to the entire urban population. (Source: Prepared by the authors using information published by the SISS)

Figure 2. Average production and consumption of drinking water in the last ten years (2004-2013). Prepared with information on SISS reports of production and billing.



consumption over the past ten years (2004-2013).[3] On average, considering the population served by sanitation companies, the estimated allowance per capita is 139 l/day[4] (138.5 and 138.9 for 2012 and 2013 respectively), with a maximum of 531.4 l/day per inhabitant for the Aguas Manquehue company(which supplies water to the eastern section of Santiago) and a minimum of 70.4 l/day for the area of Melipilla Norte (2013).

3. Information from the 25 main companies, which together provide sanitation and drinking water services for 99.4% of the clients in Chile's urban zone.

4. 1 m^3/s = 86.400.000 l/day

Urban sector coverage is substantially higher than in rural sectors. Drinking water coverage through the rural drinking water system is in the order of 70-80% (the value depends on the estimated size of the rural population). However, WHO-UNICEF cites Chile as having achieved the greatest reduction of the gap between urban/rural drinking water coverage for the period between 1900-2012 among countries with over 95% coverage in urban sectors in 1990 (UNICEF/WHO, 2014).

Drinking Water Quality

Drinking water quality is normally controlled by current regulations and is available through the SSS, which provides a record of divergences from drinking water parameters (NCh 409/1 Of. 2005) (SISS, 2014). To obtain a general notion of the main areas of non-compliance, a sample of five months between February 2012 and March 2014 was analyzed. For this period, a total of 156 incidences of divergences were found out of a total of 81,725 measurements, meaning that fewer than 0.2% of the samples measured failed to meet the standard. Table 1 presents a summary of the parameters whereby the divergences and locations affected were identified. The highest percentages of divergences in relation to the number of times the parameter was reported were sulfates (1.37%), arsenic (1.21%), suspended

Table 1. Non-compliance with drinking water quality parameters

Parameter	Norm	Units	Deviances			Locations		
			Total	Deviances TKTK	%	Northern Zone	Central Zone	Southern Zone
Arsenic	0,03 0,01	mg/L	1906	23	1,21	Alto Hospicio, Diego de Almagro, Huara, El Salado	Barnechea, Lampa, Quilicura, Chacabuco	
Bromodichloromethane	0,06	mg/L	1897	1	0,05			Coronel
Free residual chlorine	0,2 to 2	mg/L	1917	8	Northern Zone	Central Zone	Southern Zone	Empedrado, Constitución, Lebu
Chlorides	400	mg/L	1900	7	0,37	Copiapó, Totoralillo		
Total coliforms	Absence	-	1917	10	0,52		Barnechea, Valdivia de Paine, Los Álamos, Los Molles	Labranza, Pillanlelbún
True color	20	Pt-Co	1912	1	0,05			Porvenir
Flouride	1,5	mg/L	1907	5	0,26	Copiapó, Caldera	Maipo Laguna Negra, Coinco	
Total iron	0,3	mg/L	1903	5	0,26	Totoralillo	La Ligua	Iloca
Total manganese	0,1	mg/L	1901	5	0,26	Totoralillo	La Ligua	Bulnes
Nitrates	50	mg/L	1899	18	0,95	Chañaral, Caldera, Copiapó	Quillota, Lo Aguirre	
Smell	No smell	-	1906	1	0,05		Puchuncaví	
pH	6,5 to 8,5	Units	1889	6	0,32		Santo Domingo, Lampa	San Pedro de la Paz, Punta Arenas
Proportions of nitrates +nitrites	1	Proportion	1900	13	0,68	Caldera, Chañaral	Lo Aguirre	
Taste	No taste	-	1904	1	0,05		Puchuncaví	
Total suspended solids	1500	mg/L	1899	22	1,16	Arica, Copiapó, Caldera, Chañaral, Tierra Amarilla		
Sulfates	500	mg/L	1899	26	1,37	Caldera, Chañaral, Copiapó, Inca de Oro, La Tirana, Tierra Amarilla		
Turbidity	2	mg/L	1917	3	0,16	Antofagasta,	Los Molles	
Trihalomethanes	1	Proportion	1898	1	0,05			Coronel

Source: Prepared by the authors with information published by SSS (www.siss.cl) solids (1.16%) and nitrates (0.95%). Non-compliance regarding sulfates and suspended solids was mostly found in the northern zones, while non-compliance regarding arsenic and nitrates was concentrated in both the northern and central zones of the country. In the southern zone, non-compliance for the months analyzed was marginal compared to the northern and central zones.

One of the contaminants of drinking water sources that has caused the greatest concern in recent years has been arsenic. The cases of the cities of Antofagasta and Calama became known in the 1970s when coagulation-flocculation with ferric chloride process plants were built (Sancha, 2006). In fact, exposure to arsenic in Antofagasta has been essential to world science as a case study for elucidating the effect of arsenic ingestion on human health (Ferriccio, 2006). Recently, the maximum permitted arsenic concentration in drinking water was reduced from 0.05 to 0.01 mg/l, which has led sanitation companies to adopt new measures to comply with this regulation while meeting the growing demand for drinking water. Figure 3 presents a summary of the drinking water systems that have adopted arsenic reduction technology. Plants built in the 1970s continue operating with coagulation-flocculation processes with ferric chloride, and their systems have been recently optimized to meet the more stringent limits (Granada, 2003). In recent years the setting up of desalinization plants in Antofagasta (Edwards, 2012) has served to control the concentration of arsenic in the city. Desalinization plants produced 1.3 m^3/s for drinking water and water for mining (in equal parts in 2010 in the Antofagasta region); it is estimated that by 2019 the production of drinking water through desalinization will increase 2.7 times while production for mining (the primary economic activity in the region) will increase 6.4 times. It is important to note that certain drinking water systems with sources with levels of arsenic above current standards have not required the implementation of specific arsenic removal processes beyond diluting with sources with a lower arsenic content. Nevertheless, in order to meet the growing demand for water, sources with arsenic will presumably have to be used and therefore systems for their control will have to be implemented.

The literature identifies contaminants other than arsenic in drinking water sources that will require attention in the near future. These are:

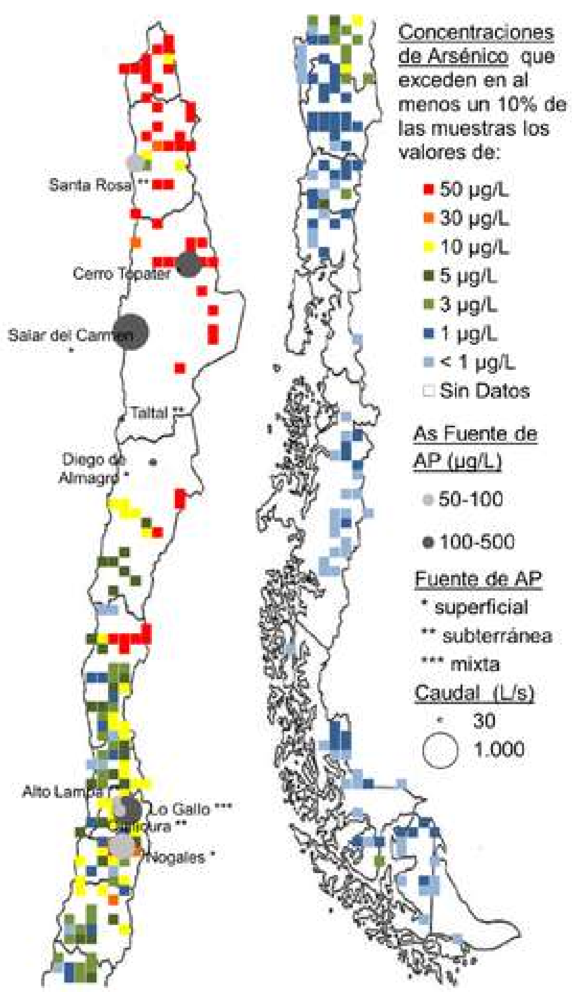
- **Boron:** in northern Chile there are drinking water sources with high boron levels. The highest level recommended by the WHO for boron in drinking water is 2.4 mg/l (WHO, 2011), yet Chilean drinking water standards do not yet include this parameter. Given the difficulty and cost of removing boron from drinking water sources, the WHO recommends that each country carefully set its own parameters based on the different sources of exposure . A study recently undertaken in the city of Arica between 2006 and 2010 (Cortes, 2011) measured a range between 0.22-11.3 mg/l of boron in public drinking water systems, with a median of 2.9 mg/l in a total of 173 samples. The same study found that boron concentrations in urine (r=0.64) correlated positively with the boron levels measured in the homes of the individuals who participated in the study. The study recommends that systematic measurements be taken and that this parameter be included in Chilean drinking water standards.
- **Perchlorate:** Exposure to this pollutant is related to thyroid malfunction (Brechner, 2000). Chile is one of the few countries where naturally occurring perchlorate has been detected in soil and water, primarily in association with nitrate deposits. Although the WHO has yet to include recommendations for perchlorate (WHO, 2011), its regulation is subject to debate in the United States and is on the legislative agenda. The state of California currently stipulates a maximum value of 6 ug/l, and there is pressure to lower it to 1 ug/l. There are still very few measures in Chile, but once further monitoring are carried out, areas in the north of Chile will be found to have levels of over 6 ug/l. A recent study measured levels of 1480 and 744 ug/l respectively in the areas of Pica and Canchones (Calderón, 2014). An earlier study (Téllez, 2005) found concentrations of 114.6 and 0.5 ug/l of perchlorate in drinking water sources in the cities of Taltal, Chañaral and Antofagasta. (Téllez, 2005)
- **Other pollutants:** There is a currently concern about the micro-pollutants present in

drinking water sources into which treated wastewater is discharged. Although concern has traditionally focused on the presence of organo-chlorate compounds, the presence of pharmaceutical compounds and personal care products in drinking water has recently elicited concern. Mainstream literature does not provide systematic measurements of this type of compounds in Chilean drinking water, probably due to the fact that methods for their quantification are not widely available.

Sanitation and environmental aspects: outlook: The analysis of water in cities cannot be separated from the basin in which it originates. On the one hand, the basin imposes hydraulic and biogeochemical conditions that determine the particular challenges to the quality and quantity of water available for a city These conditions may be natural (e.g. geological) or man-made (e.g. mining and industrial activities and energy production). On the other hand, the city has a metabolism that consumes resources, generates residues and discharges elements that may significantly affect the quality and quantity of water in its basin, thereby creating a complex interaction between urban systems and their basins, turning the latter into their natural units of analysis. The sustainability of treatment systems to provide drinking water certainly depends on the quality of its sources, while the true effect of discharges of treated wastewater clearly depends on the characteristics of the receiving water bodies. For example, in February 2014, of a total of 278 wastewater management systems (including treatment and supply plants), 20 (~7%) failed to meet the standards required by current norms. Nevertheless, there is no available information for the specific evaluation of the environmental impacts of this non-compliance. In this respect, it is important to recall that Chile has only recently begun the process of defining secondary quality norms for hydrological basins. These norms will not only allow increased regulation of wastewater and drinking water treatments plants but will also define goals for rainwater management and quality control.

Consequently, there is still a long road ahead before a database is constructed to achieve a better understanding of the processes that regulate interactions between the city and its basin.

Figure 3. Main Treatment Plants in urban sanitation services that include arsenic reduction processes (Source: Prepared by the authors; information on surface and groundwater quality, DGA and PTAS, Ahumada, 2014).



3. Sustainable Rainwater Management

Urban population growth in Chile has led to many similar urban developments during the second half of the 20th century; Santiago alone was urbanized at a rate of 8 km^2/year (Fuentes and Sierralta, 2004). This growth has produced radical changes in the hydrology of natural basins, which in turn has translated into problems such as flooding, changes in riverbeds and the pollution of receiving water bodies (Estelle et. al., 2012). Moreover, unplanned territorial occupation has forced housing and public and private infrastructure to be built on riverbeds, gorges, wetlands, lowlands and areas subject to river flooding. These changes translate into periodic flooding problems in various Chilean cities and costly investments in infrastructure to solve them.

Below is a brief outline for rainwater management designed to address these problems in Chile. It begins with a brief description of the history and current situation of rainwater management in the country, followed by the new approaches and recently incorporated tools that will make it possible to take a step towards better urban drainage management. Lastly, future challenges are outlined.

Rainwater Management in Chile

Urban drainage dates from the beginning of the 19th century when it was necessary to solve the problem of wastewater flowing through open ditches. During this period, the sewerage and rainwater collection systems in downtown Santiago were built, in 1906 (Bertrand, 1908). Subsequently and until the 1960s, networks of collection units, intended to drain both wastewater and urban runoff with a significant return period were built in various cities throughout the country. In the 1970s and particularly the 1980s, rainwater became a secondary problem to drinking and wastewater. In 1992, its management was assigned to the municipalities due to the lack of legislation on this issue.

The 1997 Rainwater Law Number 19,525, makes the state responsible for drainage systems and rainwater drainage in populated centers. Each of these systems is separated into a primary and secondary network, managed respectively by the Ministry of Public Works (MPW) and the Ministry of Housing and Urban Development (MINUH). The Law created the Directorate of Hydraulic Works (DHW), tasked with creating Master Plans (MPs) for urban drainage and checking the connections between the secondary and secondary network. Subsequently, in 2000, the Subdirectorate for Rainwater (now called the Urban Riverbed and Drainage Division) was created to evaluate the drafting of master plans, and the design, construction and use and conservation of rainwater works in conjunction with the MPW and MINUH.

The 33 MPs already created together with others at the development stage cover cities from all over the country that are home to 85% of the population. They have been transformed into a rainwater management guide, mainly from the perspective of the primary network. The MPs define primary and secondary networks and contain basic hydrology and hydraulics studies, in addition to the technical and economic analysis of various management alternatives for the primary network. For its part, the MINUH, through the regional Housing and Urban Development Services offices, has established a series of norms for secondary networks typically associated with housing developments. In particular, MINUH has proposed design guides for helping urban developers and construction companies develop and implement urban drainage (MINVU, 1996; MINVU, 2008).

Nevertheless, both MPs in particular and urban drainage management in general have a number of shortcomings closely linked to the widespread inaction before Law 19,525 was passed and to the old paradigm that regarded urban runoff as a nuisance and even a threat rather than as a potential resource to be protected. Some of these drawbacks include the following: (1) lack of an integral vision in which the basin rather than the administrative unit is the key territorial unit, (2) lack of environmental objectives (i.e. preserving riverbanks, controlling the quality of water in the receiving bodies), which depend on the reality of each basin, (3) low or nonexistent levels of spatial integration (from domestic to regional) in alternative runoff management, since the focus of the MPs is the primary network, (4) emphasis on the use of conduction solutions rather than techniques and public works based on infiltration and storage, (5) weak or nonexistent links with the Land Planning Instruments (LPIs) and (6) despite the fact that thesystems are structural in nature, the measures adopted are non-structural and flood area management techniques are only partially addressed.

Sustainable Urban Drainage Planning and Management

The above problems require integrated, long-term management that will incorporate the various spatial scales and actors involved.

To this end, in 2013, the MPW published the Urban Drainage Manual (UDM) (MOP-DOH, 2013), which addresses this task by bringing together into one document all the concerns, interests and responsibilities of the stakeholders involved (i.e. private companies, urban developers, municipalities, attorney generals and sanitation companies) This document applies to the whole country and guides stakeholders' participation in the planning, design, operation and conservation of urban drainage systems. Since the UDM represents the state of the art of rainwater management in Chile, its main focuses and standpoints are summarized below. The summary is recommended for further details on any issues of interest especially with regard to public works design.

The Foundations of Urban Hydrology

Urban development implies the large-scale removal of the top layer of soil, vegetation and the natural drainage network and their replacement with impermeable areas (i.e. streets, houses and urban infrastructure). This entails the loss of the natural capacity for infiltration, storage and evaporation-transpiration, essential processes in the natural water balance and an increase in direct surface runoff (Akan and Houghtalen, 2003). This, together with the construction of an artificial drainage network, involves a change in the local hydrology and flow rate systems, creating larger flow rates and runoff volumes during precipitation and losses in the base flow. This alteration can be seen in the frequency curves and flow-duration curves before and after the urbanization process (Nehrke and Roesner, 2004; Rohrer and Roesner, 2006). These changes not only cause urban flooding but also lead to radical but more silent impacts on the receiving courses and water bodies and the ecosystems that develop therein (i.e. erosion and sedimentation of riverbeds, washing of diffuse urban pollution, frequent collapse of unitary systems and so on) (Akan and Houghtalen, 2003; UDFCD, 2013). In fact, the greatest differences in flows and frequency of occurrence in relation to the natural situation occur precisely with small, frequent amounts of rain (Roesner et al., 2001; Nehrke and Roesner, 2004). They are therefore the ones that are largely responsible for the environmental impacts described earlier, despite the fact that they do not usually cause large-scale flooding or damage to people and infrastructure.

Urban Drainage Policies

The consideration of the bases of urban drainage previously identified has led to the development of rainwater policies structured around a central guiding policy: *maintain or restore each component of the water cycle to its natural level while simultaneously considering rainfall as a resource that may be polluted and affect receiving waterways and water bodies rather than as a residue or a threat in itself.* Adhering to this policy largely ensures proper rainwater management and the control of the many problems arising from it. Operationally, the following specific policies have been proposed to guide the development of a variety of urban drainage activities at different spatial scales, including (1) drafting, updating and modifying MPs, (2) projects to mitigate or improve existing urban developments and (3) urban drainage projects for future urban developments:

1. The planning, design and management of rainwater systems are integral activities to be undertaken at the basin level, transcending administrative divisions and addressing the process from downstream. This prevents transferring problems downstream and encourages the sustainability of long-term solutions.
2. In new urban developments, levels and volumes of surface runoff and loads of pollutants must be maintained or reduced during both the construction and operating phases.
3. An integral drainage system entails, as far as possible: (1) local household control, (2) local retention in public soil, (3) slow surface transport, (4) larger-scale storage in public soil, and (5) controlled conduction through transport elements and its subsequent discharge into receiving waterways and bodies of water.
4. The natural drainage network must be respected and become part of the urban drainage network during the urbanization process. The flood zone must not be occupied for T=100 years, allowing the characteristic movement of basins within it and ensuring its geomorphological integrity.
5. All existing urban territory or territory considered for territorial planning must have a

MP linked to the LPIs that considers the related basin(s)(s). The master plan should explicitly include (1) aspects relevant to land planning and management, (2) the flood zone T=100 years for riverbeds and gorges within urban space, (3) a definition and description of the primary network, and (4) conditions for unloading and evacuating secondary and household networks.

The new rainwater networks should be independent and separate from wastewater unless their proximity is technically justified.

1. Urban drainage should seek to minimize the disfunctionalities, disorders and environmental effects caused by frequent rainfall and provide safe management of less frequent flooding to prevent human and infrastructure losses. The public works chosen to meet these goals should not be detrimental to the urban landscape.
2. Rainwater management should minimize the impact of runoff on the quality of surface and underground receiving bodies and their environmental integrity .
3. The rainwater management system and its various elements should be periodically maintained to guarantee the service level considered in its design.

Policy 1, largely absent from rainwater planning and management, is crucial to a sustainable drainage system. It seeks to change the old paradigm of rapid drainage through collectors that drain larger conduction elements, which become obsolete when upstream contributions increase. By contrast, the new paradigm, based on downstream management, allows one to reduce the risks of flooding and effectively use the natural drainage network within the flooding zone. This can be achieved by imposing discharge conditions from the receiving riverbeds and bodies of water upstream to the local scale. This encourages the spatial integration of various storage, infiltration and conduction mechanisms, particularly the use of local works compatible with the urban landscape and alternative uses of green or recreation areas known as Sustainable Urban Drainage Techniques or Low Impact Development (UDFCD, 2013). Lastly, this management scheme makes it possible to define similar restrictions on the quality of discharges from upstream, eventually enabling water quality objectives to be included in urban drainage systems as is done in developed countries (Dodson, 1999).

Policies 7 and 8 deal precisely with the issue of recipient water pollution by washing pollutants and discharges from unitary systems. To this end, the concept of catch amount (CA), defined as a significant portion of average annual runoff (i.e., 80% – 90%) to be controlled by infiltration or retained and released over an extended period of time (6 – 40 h) (UDFCD, 2001; WEF-ASCE, 1998) is introduced. Retention of this amount allows the majority of storms to be controlled, or at least the initial, most polluted portion of major runoff events, known as initial washing or first flush (Stenstrom and Kayhanian, 2005; Froehlich, 2009). One is thereby able to act on the volume of annual runoff responsible for a significant portion of diffuse urban pollution and a large number of unitary network discharges. Precipitation for the CA calculation has been calculated for various cities and areas in Chile (MOP-DOH, 2013; Padilla, 2014).

Benefits of Sustainable Urban Drainage

Planning and management of sustainable urban drainage yields many benefits beyond flood control and its impact. A well-planned and managed drainage system is typically associated with harmonious, regulated territorial planning and growth, which means shared benefits for both activities. These benefits tend to be more relevant

Figure 4. Identification of household (pink), secondary (yellow), primary (green) and natural (blue) networks within the urban environment.

Table 2. Organization of urban drainage networks, specific features and common complementary projects

	Networks			
	Household	Secondary	Primary	Natural
Persons responsible and major players	Private citizens, real estate construction companies	MINUH, municipalities, real estate companies, EE.SS1	MOP, EE.SS	MOP, MBN2, DGA3
Specific features	Roofs, pavement, patios	Streets, green areas, parking lots, sidewalks	Riverbeds, parks, squares	Rivers, lakes, flood plains
Objectives	Local household control	Slow transport and storage in public soil	Storage in public soil, controlled conduction and discharge to natural network	Receiving bodies of water
	Drainage projects			
Infiltration	Green roofs, rain gardens, wells	Permeable pavements, wells, ponds, drainage ditches		
Storage	Barrels, small ponds	Ponds, lagoons	Ponds, lagoons, wetlands	
Conduction	Rivulets and canals, drainpipes	Drainage ditches, sumps, ditches, collectors.	Urban riverbanks, canals, collectors, discharges	Rivers, estuaries, lagoons, lakes, sea
	Design conditions			
Internal control	Do not storm flood dwellings for 100 years. Do not storm flood outside pavements for 2 years.	Do not exceed the foundation level for rains for 100 years. Maximum flooding width in streets limited for 2 years' rain.	Do not cause rain flooding for 100 years. Do not cause rain-related inconveniences for 2 years.	Do not increase rain flood areas for 100 years. Do not urbanize at-risk zones. Control quality effects.
Discharge conditions	Retain and use catch amount. Maximum discharge rate according to MP.	Retain catchment water for the entire drainage area. Maximum discharge rate according to MP.	Control quality and quantity effects. Maximum rate to be discharged according to MP.	

1 Sewage Companies, 2 Ministry of National Assets, 3 Directory of Water

when the perspective of civil engineering, the environment and transport, hydrology, urban planning and architecture, sociology, law, public health, economics, geography, ecology and landscaping are included. Benefits include: (1) fewer problems of interaction between upstream and downstream areas; (2) lower construction, infrastructure and road maintenance costs; (3) improved vehicular traffic; (4) improved quality of urban runoff and receiving water bodies and public health; (5) protection and enhancement of environmentally sensitive areas; (6) availability of more open spaces and green areas at a lower cost; (7) sustainable behavior of the aquifer after urbanization; (8) strengthening and improvement of initiatives where drainage is an input (renovation, public health and recreation, road infrastructure programs and so on).

Urban Drainage Network Design

The urban drainage system is a global system formed of four converging networks: the household, secondary, primary and natural networks. The design of these networks seeks to organize its elements and public works in order to meet the global objectives of the system while considering the conditions under which it operates. Each network requires the explicit identification of: (a) its operating and downstream discharge requirements, (b) design ideas for the sizing and control of the operation, (c) the organization and sizing of the operation, (d) works needed to meet operation and discharge requirements. Table 2 shows the relationship between the networks, major players and persons responsible, their specific features and examples of typical drainage systems. Moreover, their objectives in relation to policy 3 are defined.

Local and Household Network Design

The household network, the system inside private property upstream from the public system (e.g. businesses, dwellings condominiums), receives 60-80% of rainwater, which has a high impact on the urban complex (Figure 4). The drainage system in this network must be designed, built, operated and preserved by private individuals, bearing in mind the conditions of the MP, municipal ordinances and rules, and MINUH and LPI indications for the zone. It is also proposed that at the very least, the design conditions defined in.

Secondary Network Design

The MP defines the secondary network as the one located upstream of the primary network. Its function is to control the water received from urban developments, property and eventually discharge them into the primary network . Together with the discharges from the household network, this network directly receives 20-40% of rainwater, mainly on streets and sidewalks (Figure 4). Thus, practically all urban runoff can be managed, at least partially, by this network. A typical feature of secondary networks are sumps which remove runoff and channel it into other drainage works. These works are sometimes not only used for underground conduction, but also for surface conduction and infiltration or storage, which ensures the retention and/or slow transport of runoff.

Design of the Primary Network and its Discharge into Channels and Receiving Water Bodies

The primary network defined in the MP is the central network of the urban drainage system that channels runoff from household and secondary networks into receiving waterways and water bodies (rivers, lakes and sea). Although this network includes artificial transportation features, it is essential that it also include the natural drainage network as well as regulating features such as lagoons, ponds and wetlands. Unfortunately, large, expensive works with a limited useful life (e.g. collectors, artificial canals, etc.) have typically replaced the dendritic drainage systems formed of brooks, riverbeds and rivers that naturally converge on large water bodies. This is avoidable if runoff volume is limited from downstream upstream by adopting infiltration and storage mechanisms rather than just conduction features. Territorial planning, in conjunction with the MP, also determines the characteristics of the primary network, its cost, capacity and operation, since it makes it possible to implement a set of non-structural measures that limit occupation of the natural drainage system and its flood zones.

Challenges to Urban Drainage in Chile

Developing and implementing a new form of urban drainage constitutes an important step in the integrated management of urban waters and the basins in which cities are located. The creation and improvement of regulatory instruments for urban drainage to strengthen this new development entail the following challenges:

- Improving hydro-meteorological information and its use in design and analysis applications. It is particularly important to better understand the space/time variability of rain.
- Defining the channel flood zones, which serves as an essential input for the downstream management described earlier.
- Using distributed modeling and continuous simulation tools, which will make it possible to simulate and better understand the hydrological and environmental functioning of the entire urban system and its components, facilitating their management.
- Implementation and monitoring of pilot programs to validate and/or improve the design of drainage works and understand their interaction with the community.
- Formally incorporating water quality aspects in which the discharge of urban runoff and dumping of unitary systems is regarded as a pollution event. This would lead to more complete urban drainage planning and management.
- Boosting the role of local reality in the definition of the specific goals of the MP in order to achieve a healthy situation in which "global tools [are used] for local problems".
- Educating the community about urban drainage problems so that people understand the operation, goals and benefits of the various works. The community is the user, beneficiary and, to a certain extent, chiefly responsible for these works.

4. Climate Change and Security of Supply

Geographically speaking, half of mainland Chile's area is associated with relatively severe climate change projections. From a demographic

Figure 5. Projected annual average temperature change during the historic period (1991-1990) for three emission scenarios: RCP 2.6, RCP 8.5 and SRES A2. (Source: Ministerio de Medio Ambiente, 2013)

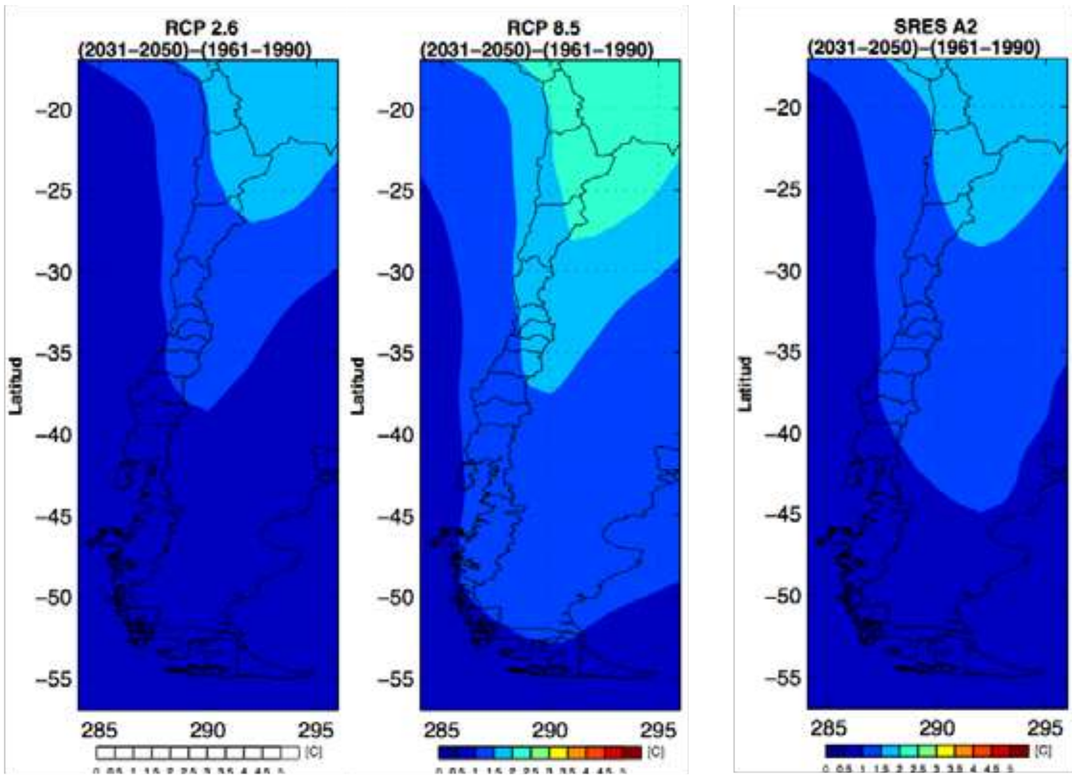


Figure 6. Projected annual average temperature change during the historic period (1991-1990) for three emission scenarios: RCP 2.6, RCP 8.5 and SRES A2. (Source: Ministerio de Medio Ambiente, 2013)

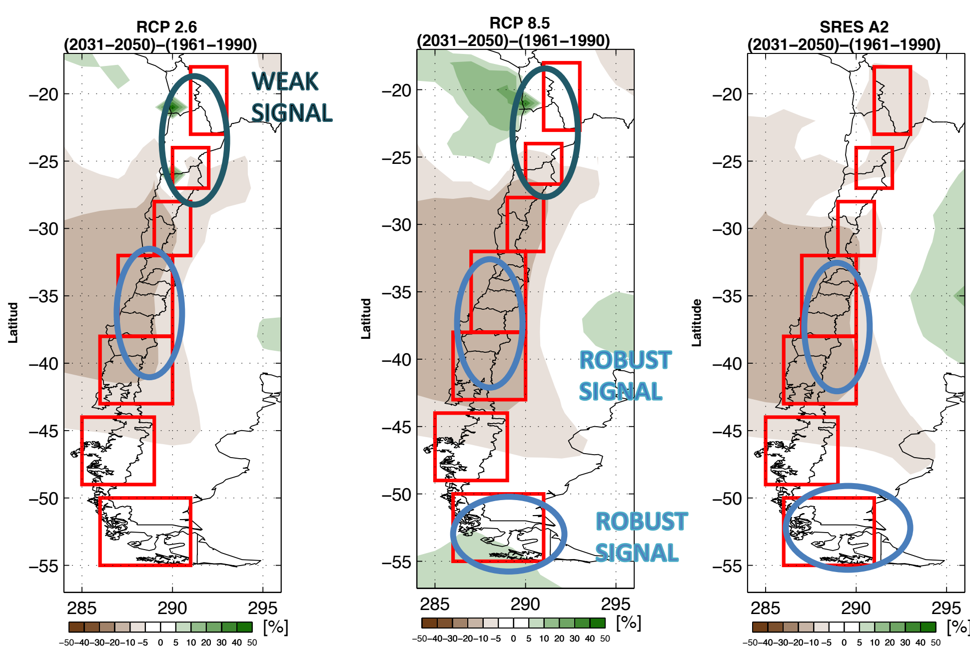
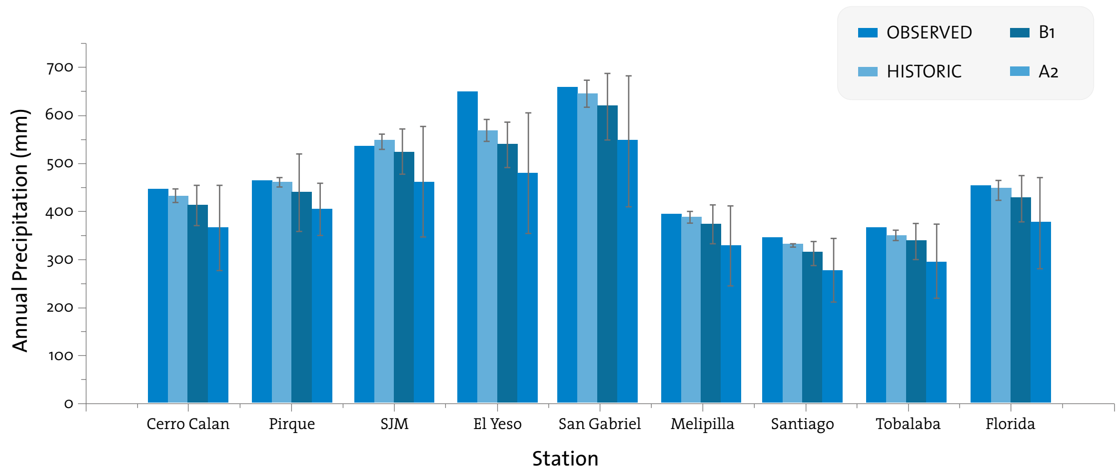


Figure 7. Projected changes to annual rainfall during meteorological seasons in the metropolitan region of Santiago de Chile. Source: McPhee et al., 2014

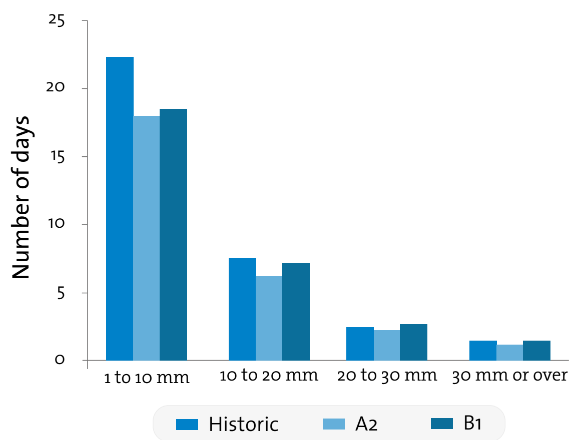


point of view, approximately 50% of the national population, just over 8 million people, live in cities where climate change projections indicate not only increased temperatures but also a significant decrease in precipitation towards the second half of the 21st century. This situation is superimposed over other rapid changes such as the increase in the urban population, the loss of agricultural land, and the urbanization of areas near the mountains, resulting in a situation where it is possible to envisage significant changes to the hydrological conditions that determine access to water supply sources, and the population's degree of exposure to extreme hydro-meteorological events that affect people's quality of life, the reliability of urban infrastructure and provision of public health and transport services, among others. Figures 5 and 6 show the temperature and precipitation projections for Chile in the second half of the 21st century (Ministerio de Medio Ambiente, 2013). In terms of temperature, more severe warming is expected to occur in northern Chile in the order of 2°C more than the historical average. Where precipitation is concerned, the extreme north and south areas do not show significant changes, although a 15 to 30% decrease in average annual rainfall for the Copiapó (Latitude 27° S) and Puerto Montt (Latitude 41°S) can be observed. It is important to note that these estimations are drawn from various global general circulation models (GCM), and that projections of individual models vary. However, all the available models used in this analysis[5] foresee a reduction in rainfall towards the end of the first half of the 21st century, adding a level of reliability to these projections. They can therefore be used as base assumptions for the analysis of water issues and the evaluation of adaptation measures.

A number of studies have been conducted to understand the scale and effects of the projected climate changes on various human activities. At the urban level, McPhee et al. (2014) provide a specific analysis for the city of Santiago, based on the analysis of projections for the daily rhythm of temporal resolution of 10-15 general circulation models (depending on the variable studied) with climate scenarios A2 and B1 presented in the IVth IPCC report. Projections for the years 2045-2065 were made for a number of locations where meteorological stations exist, using spatial and temporal scaling techniques. From the point of view of temperatures, a tendency towards rising mean, maximum and minimum temperatures has been confirmed, with monthly deviations of between 1.5 and 2°C. In some cases, the deviations are greater during the winter and spring months (June to November) with less warming being observed during the autumn months.

5. 21 General Circulation Models, included in theCMIP5 study (http://cmip-pcmdi.llnl.gov/cmip5/).

Figure 8. Changes in daily rainfall distribution in the the Quinta Normal meteorological station, located in the center of Santiago, Chile. (Source: McPhee et al., 2014).



A simplified analysis allowed McPhee et al. (2014) to estimate changes in the position of the 0° isotherm, resulting in increases of approximately 100 m in the monthly average of this parameter during the winter months. Garreaud (2013) presents an analysis of warm storms in Central Chile, showing that for certain historical events, a rise of the For the Rio Maipo's high basin, which drains towards Santiago, an increase of 100 m in the average isotherm on rainy days could increase the potential runoff average during these events by 50%. Although this is a preliminary analysis that must be complemented by other studies, it outlines the threats from floods one could expect due to climate change, which is complemented by the following analysis of rainfall.

A decrease in the annual average has also been observed, even though the discrepancy between models is large enough for historic values to fall within the range of expected variation in most cases. For the meteorological seasons analyzed by McPhee et al. (2014)an average reduction of 25% in annual mean rainfall is expected for the period from 2045 to 2065 (Figure7).

One aspect worth noting in this study refers to the change in the distribution of frequencies of days with daily rainfall located in various classes. Rainfall events were grouped according to the amount of rain accumulated in 24-hour periods. It follows from this analysis that the reduction of total annual rainfall projected by future models is fundamentally expressed as a reduction in the frequency of days with slight or moderately intense rainfall (daily rainfall > 30 mm). Conversely, the frequency of days with more intense rainfall (daily rainfall > 30 mm) remains fairly constant according to the simulations of future climate scenarios (Figure 8).

The hydrological changes it is possible to foresee obviously depend on the specific local conditions of each city and its contributing hydrographic basin. Furthermore, the degree of severity of the impact of hydrological changes on the urban water system in each case is a function of the severity of the hydrological changes, combined with the nature of the adaptation measures each city may implement. For example, for the city of Santiago, Meza et al. (2014) showed that on the basis of a numerical model exercise, the decrease in the average supply in the health and agriculture sectors is slight, even for scenarios with greatly reduced rainfall. For example, for scenarios with a 40% reduction in rainfall, the reduction of the average supply during a 30-year window would be approximately 10% for the sanitation and agricultural sectors (with the agricultural sector suffering the greatest reductions in supply). On the other hand, the minimum supply during the same time window is more heavily impacted than the average. Thus, for example, scenarios with a 20% reduction in average annual rainfall entail a 25% to 50% reduction in the minimum annual supply in the sanitation and agricultural sectors respectively.

How Urban Water Systems Adapt to Climate Change Context and Examples from the City of Santiago de Chile

Adaptation to climate change requires first answering a series of structural questions that will help design adaptation options and the process of implementing these options. The first question concerns the need for adaptation. Why do the Urban Water Systems (UWS) need to be adapted? A key concept for answering this question is Water Security. In short, UWSs must be adapted when there is a climate event that threatens Water Security. This adaptation must either preserve or improve

Water Security within the limits of the city, ideally without harming other users (whether productive or otherwise) of the water in the basin. Once this first problem has been dealt with, a second key question involves the adaptation process itself: How can the UWSs be adapted? This can in turn be broken down into a series of questions such as: What options for adaptation are available? Who should adapt? When should this adaptation take place? And lastly, how can the adaptation process best be implemented?

Water Security and the Need for Adaptation

Climate change in UWS may occur in the two main dimensions of water in cities: water as a resource and water as a threat. As a resource, the availability of good quality water is the basis of the wellbeing and way of life of a city´s inhabitants. It is also essential to the many economic activities undertaken in and around cities including periurban agriculture, the food and beverage industry and other industrial activities. Meanwhile, excess or insufficient water can give rise to threats such as the concentration of pollutants (with negative effects on health), the lack of a proper flow of water for drainage systems and damage to physical assets related to flooding.

How can Urban Water Systems be Adapted?

Assuming the need for adaptation, the problem is therefore to decide how to achieve this adaptation. In order to answer this question, it is important to consider the different options available and once a decision has been reached about which ones are best, it is necessary to design a stage for implementing the measures including financing, the roles of the various players involved and the times when measures must be implemented.

Using the Water Security framework helps identify adaptation options for addressing a particular aspect of security that has been threatened by climate change. In terms for example of access to adequate amounts of water, we find ourselves with options that have to do with the supply of water, such as water transfer between sectors, reuse, the construction of storage works and improvements in the distribution systems. On the other hand, it is also possible to redefine what is understood as an "adequate" amount of water supply by incorporating options that alter water demand without reducing the wellbeing or productive utility achieved through water consumption. Measures such as these are associated with changes in behavior resulting from effects on rates, awareness campaigns, or regulatory changes that may affect the availability of technologies or consumption habits.

With regard to water distribution, the type of options available will depend on the relative position of cities within a basin (Vicuña et al., 2014). For example, a city located near a headwater basin has a limited number of options, associated, for example, with transferring water to other sectors that use water or building storage works. Cities in coastal zones can use this type of options, but may also choose options such as desalinization or transferring water from other basins.

The city of Santiago in Chile is a good example of cities that have limited capacities for adaptation measure due to their proximity to mountains. Santiago is the largest city in Chile, and home to approximately seven million people producing nearly 40% of the country's GNP. Water use in Santiago is mainly residential, accounting for 73% of total consumption (SISS, 2009). Average per capita water consumption in Santiago is 150 l/day, although consumption can reach over 600 l/day when high-income neighborhoods are considered. The remaining consumption is associated with industrial and commercial uses, parks and so on. As for water supply sources, the city of Santiago is located in a region with a semiarid Mediterranean climate at the food of the Andes. The Maipo River basin is the main source of water supplies (80%) for the city. Moreover, the city depends on groundwater extraction to cover 20% of the remaining needs and to operate a dam in the mountains in order to be able to manage the differences between water supply and demand that occur within and between years.

As with other basins in the central part of Chile (Vicuña et al., 2010) described in detail above, the city of Santiago faces not only pressure to meet the demands of a growing city, but also the potential impacts of climate change. A series of adaptation options have been studied by Bonelli et al. to address the consequences of the complex water supply conditions (accepted). One option is to reduce the inefficiencies in water distribution and consumption. Currently, almost 30% of the surface water extracted fails to reach end consumers, mainly because of leaks in underground pipes. One way of improving efficiency is therefore to improve the network infrastructure. Efficiency can also be addressed through a demand-based approach, for example, through policies that encourage the conservation and efficient consumption of domestic water. According to estimates, an increase in efficiency of over 20% could be achieved through the short-term installation of more efficient accessories and appliances in households and offices (Observatorio de Ciudades, 2009).

When considering a basin perspective, the main option available to the city is to increase the proportion of water rights owned by the sanitation company that distributes water throughout the city in relation to those owned by the agricultural sector. Water companies currently own 25% of the total amount of water rights for the Maipo River. According to Bonelli et al. (accepted), this share should reach 40% by 2050 in order to cope with the impact of climate change and population growth. Transferring water rights from the agricultural sector to the urban sector has been one of the main strategies used by the city to meet the city's growing needs. In the past 40 years, the city has doubled its area and increased its population from three to nearly seven million people. Despite the fact that the total agricultural area depending on the basin has remained relatively constant, total water consumption has decreased thanks to a progressive increase in the efficiency of irrigation due to the introduction of new technologies. By way of an example, in 1997, drip irrigation accounted for less than 10% of the total area of irrigated land, increasing to over 30% by 2007 (INE 1997-2007). The majority of these water savings have been transferred through the sale of water rights, to water services in the urban sector. Water rights are a peculiar characteristic of Chile's water system, which grants private ownership of water regardless of its predicted use and land ownership (Vicuña and Meza, 2012). The purchase of water rights is one of the main new sources of water that water companies have historically used to supply the growing population and the prevailing dry climate (ANDESS, 2014). Overall efficiency of irrigation in the basin remains low (approximately 50%), which suggests that this water transfer strategy could continue growing in order to offset possible supply shortages due to climate change.

In order to evaluate the various adaptation measures that could be implemented by the urban sector and other water users in the Maipo River basin, a project called MAPA (Maipo Plan de Adaptacion (Maipo Adaptation Plan) is being developed, which is designed to link the development of an adaptation plan to variability and climate change in the Maipo River basin. More information on this project, funded by the International Development Research Center (IDRC) is available at <http://maipoadaptacion.cl/>.

5. Conclusions

Over the past four decades, Chile's urban water sector has achieved significant progress as regards water coverage and quality and in wastewater treatment levels in the past 15 years. This progress has been helped by the country's economic stability and public policies that have prioritized the decentralized management of health services. Although improvements in the efficiency of sanitation companies' management has been verified, the theoretical reductions in rates this should entail have not been verified. The population with the lowest income receives cross-subsidization that helps to relieve their situation and has made the privatization policies implemented in recent years feasible. Likewise, the robustness of the supply system in many cities has been enhanced by the possibility of acquiring water use rights from other users, which in practice has meant transfers from the agricultural to the urban sector.

Despite the progress described above, there are still enormous challenges to be addressed. In certain regions, the arrival of industrial and mining sectors has constituted a threat due water transfers to this activity, although in the case of major cities in the north of Chile, there have been institutional agreements that have made it possible to guarantee domestic supply. In the central zone, companies such as Aguas Andinas and VSWC have achieved high coverage and credibility, and even in drought situations such as the one experienced by Chile since 2011, no problems have arisen in supplying the majority of the population. One source of concern are the smaller periurban populations, which often have local supply systems not covered by larger regional companies, which are much more vulnerable to drought and other disruptions in the supply of water. In some cases these populations have had to be helped by tanker trucks, resulting in a significant deterioration of the population's quality of life.

Rainwater management in Chile continues to revolve around the construction of large infrastructure works to drain water, with less being invested in water retention and infiltration works. Likewise, non-structural measure such as better territorial planning are underrepresented, partly because of the conflicts and gaps in the definition of the competences of various government entities.

Lastly, the climate change perspectives envisaged for a significant portion of Chilean territory suggest that progress must be made on a nationwide adaptation agenda that will seek to preserve current average supply levels and attempt to improve the robustness of systems during periods of drought. This adaptation agenda should of course consider local realities, but must be guided by the common principles of reliability and the preservation of ecosystem services within the concept of increasing global water security.

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